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THESIS

DESIGN OF A SYSTEM TO MEASURE
RADAR CROSS SECTION

by

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Design of a System to Measure Radar Cross Section

by

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ABSTRACT

The instrumentation of a Nike-Ajax radar to perform real-time radar cross section measurements of airborne targets is discussed. Measurements include those based on both radar automatic gain control voltage and radar video pulse peak voltage.

Instrumented signals within the radar are conditioned and sent via transmission lines to a CI-5000/SDS-9300 hybrid computer. Computed radar cross section and associated analysis information are returned to a display console in the vicinity of the radar.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	Effective antenna aperture
ac	Alternating current
AGC	Automatic gain control
C	System constant
dB	Decibel
dBm	Decibel referred to one milliwatt
dc	Direct current
FET	Field-effect transistor
FFT	Fast Fourier transform
G	Gain of the antenna in a monostatic system
HP	Hewlett Packard
IF	Intermediate frequency
K	Kilohm
μF	Microfarad
M	Megohm
ma	Milliamp
MGC	Manual gain control
ms	Millisecond
μs	Microsecond
mV	Millivolt
pF	Picofarad
PRF	Pulse repetition frequency
Pr	Power received
P_{rs}	Power received from a sphere

P_{rt}	Power received from a target
P_t	Power delivered by the transmitter to the antenna
r	Radius
RCS	Radar cross section
rms	Root-mean-square
Rs	Range from the antenna to a sphere
Rt	Range from the antenna to a target
νs	Radar cross section of a sphere
νt	Radar cross section of a target
V	Volt
Vp	Processed video pulse voltage

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I. INTRODUCTION

Considerable interest exists in being able to determine the radar cross section (RCS) of an airborne target. RCS is defined by Skolnik in Ref. 1 in two different ways. The first is a theoretical definition which relates incident to scattered electromagnetic fields and is useful primarily in theoretical studies of RCS. The second is an experimental definition which may be obtained by isolating RCS in the radar-range equation:

$$\nu_t = \frac{(4\pi)^2 R_t^4 P_{rt}}{P_t G A} \tag{1}$$

where: ν_t = RCS of a target

R_t = Range from the antenna to the target

P_{rt} = Power delivered by the receiving antenna to the load

P_t = Power delivered by the transmitter to the antenna

A = Effective antenna aperture

G = Gain of the antenna in a monostatic system

In the above equation, RCS has dimensions of area, commonly square meters, although the cross section usually has only a gross resemblance to the cross sectional area of the target. RCS is usually defined to be independent of range to the target and dependent on factors such as radar operating frequency, polarization, target aspect, physical

composition of the target and atmospheric absorption. Depending upon the particular interests of the observer, RCS may differ in meaning or significance. To the radar designer it usually represents a specification which he must meet. That is, he is expected to design a radar which will detect a target having some minimum RCS at a specified maximum range. To an analyst a collection of RCS data may represent a source of information that, if properly analyzed, will provide target signature or target recognition information. The concept of the RCS system devised at the Naval Postgraduate School (NPS) was the interconnection of a radar system and a computer so that they functioned as a single system to measure radar cross sections. The purposes of the system were to be:

1. To provide a teaching vehicle for students at NPS which could demonstrate digital techniques applied to a radar system and which could be used to give students a better understanding of the measurement and analysis of RCS information.

2. To provide a capability for determining target signature data through spectrum analysis of the power returned to the radar receiver by the target.

One of the most common methods of measuring radar cross section uses an indoor radar range and a scaled model of the target. In addition to size scaling, the permittivity, permeability and conductivity are also scaled in the model. The model is illuminated with energy at a proportionally

scaled frequency and the backscattered energy is measured and used to determine RCS as a function of aspect angle. There are several advantages to using an indoor radar range. First, measurements are taken under highly controlled conditions so that backscatter from objects other than the target can be minimized. Energy sources and receivers are of high quality and can be varied in frequency so that data can be collected over a broad range of frequencies. Finally, since the model is mounted on a pedestal, the target aspect can be controlled quite accurately. The largest sources of measurement errors are due to the non-plane-wave illumination of the model due to the confines of the testing range and the scattering effects of the support structure for the model. Some dissatisfaction is centered on the validity of the model, however, It is very difficult to produce a model with scaled electrical properties which accurately simulate an aircraft. Also, time variation of RCS due to propeller or turbine modulation is unavailable in static measurements.

A second type of facility for measuring RCS is the outdoor radar range which uses a full-size aircraft mounted on some sort of support so that aspect angle can be easily changed. This method reduces many of the errors associated with the use of models in a confined area; however, other errors are introduced. These include errors due to strong returns from the large support required to carry the load of the aircraft, and background effects from surrounding

objects such as trees, buildings and the ground. Most outdoor ranges use fences of ground radar absorber to reduce unwanted backscatter.

Errors due to supporting structures may be eliminated by dispensing with the support. In the final method discussed for experimentally measuring RCS, a field radar and full-size aircraft in normal flight are used. This permits a measurement to be made of the entire aircraft as it exists under normal operating conditions in its natural environment. Implementation of the dynamic method is relatively uncomplicated since many of the special equipments such as carefully made models, target supports, absorbing fences, and anechoic chambers used in static methods are not required. One of the important constraints imposed by this method is the requirement for good equipment stability. Since calibration of the system may be effected by tracking a calibration sphere, the actual values of gains or sensitivities of the radar are not as important as the fact that they remain constant from the time the system is calibrated until RCS measurements have been completed. Atmospheric conditions are obviously a key factor in dynamic measurement of RCS. Ideally, weather conditions should be uniform throughout the testing area and identical with conditions under which calibration information was recorded. While perfect weather is not required, severe conditions such as thunderstorms, rain squalls and storm fronts will have disastrous effects on RCS measurements, especially at C-band

and above. Even under ideal weather conditions, atmospheric attenuation may be a source of serious error. Since the target is not mounted on a support, aspect can not be accurately controlled so some means must be provided for measuring it. This last method was chosen for implementation using the Nike-Ajax radar system.

II. THEORY

The experimental definition of radar cross section of a target was given in the introduction as

$$\nu_t = \frac{(4\pi)^2 R_t^4 P_{rt}}{P_t GA} . \tag{1}$$

This equation is convenient for use in the dynamic method of determining RCS of a target if a calibration procedure is used to eliminate factors which are unchanged from the start of calibration to completion of RCS measurement using a mono-static (single antenna and receiver) system. Calibration is accomplished by tracking a shape of known radar cross section and recording some measure of power received, P_{rs}, versus range to the shape, R_s. For the calibration run, RCS of the shape is given by

$$\nu_s = \frac{(4\pi)^2 R_s^4 P_{rs}}{P_t GA} . \tag{2}$$

Since the same transmitter, antenna and receiver are used for both calibration and measurement, it may be assumed that P_t, A and G are constant. Dividing (1) by (2) gives

$$\frac{\nu_t}{\nu_s} = \frac{P_{rt}}{P_{rs}} \times \frac{R_t^{\ 4}}{R_s^{\ 4}} .$$

RCS of the target is then given by

$$\nu_t = \nu_s \frac{P_{rt}}{P_{rs}} \times \frac{R_t^{\ 4}}{R_s^{\ 4}} \tag{3}$$

which may be reduced to

$$\nu_t = \nu_s \frac{R_t^4}{R_s^4} \tag{4}$$

provided that $P_{rt} = P_{rs}$. The assumptions made above are reasonably valid unless changes in radar parameters such as transmitted power, receiver gain, antenna gain or losses in the system occur. If changes do occur, a new calibration track is required.

The most commonly used calibration shape is the sphere since its RCS is easily calculated and is independent of aspect angle. Reference 2 shows that for a sphere, which is a perfect conductor and which has a circumference sufficiently large compared to the radar wavelength, the backscatter radar cross section is equal to its geometric cross section given by:

$$\nu_s = \pi r^2 \tag{5}$$

where

ν_s = Radar cross section of the sphere in square meters

r = Radius of the sphere in meters.

It should be stressed that equation (5) applies only if the ratio of the circumference of the sphere to the wavelength of the radar lies in the optical region. The optical region is defined in Ref. 1 as that region where this ratio is equal to or greater than 10.

To solve for ν_t it is necessary to record values of P_{rs} versus R_s during a calibration track using a calibration sphere. P_{rt} and R_t are instantaneously measured during a target tracking run. Since to use equation (4) P_{rt} must equal P_{rs}, a particular virtual value of R_s exists for each set of values of P_{rt} and R_t. These values of R_s and R_t together with the known value of ν_s calculated from equation (5) are used in equation (4) to determine ν_t. Thus, target RCS may be found directly for each value of P_{rt}.

Although the quantity of power received, P_{rt} or P_{rs} is not a product of most radar systems, two quantities are usually available which may be used as measures of received power. These quantities are automatic gain control voltage (AGC) and video pulse voltage. The AGC is a direct current (dc) voltage which varies monotonically with the strength of the received signal. However, it does not respond instantaneously to changes in signal amplitude. Several pulses must be received before the AGC effects a change in gain. It can therefore be seen that AGC is a good measure of average power received over several target returns. It is not a suitable parameter for calculating pulse-to-pulse radar cross section, but is very useful for computing average RCS over several returns. For pulse-to-pulse RCS calculation, the video pulse voltage with no AGC applied to the receiver may be used.

III. IMPLEMENTATION

Implementation of the system involved interconnecting an available radar system and computers to obtain a capability for experimentally measuring dynamic radar cross section parameters, computing radar cross sections of aircraft and displaying RCS information in the vicinity of the radar console. It was desired to compose a system which would accomplish the following specific objectives:

1. Display average radar cross section of a target.
2. Display pulse-by-pulse calibrated radar cross section.
3. Display a histogram of radar cross sections.
4. Display radar cross section fluctuation information.
5. Display target angle, target altitude, target heading, target speed, and a plot of the target's track.
6. Provide for complete control of data processing from the radar console after the required program had been loaded into the computer.

The equipments necessary to accomplish these objectives may be divided into four functional groups. They are the radar, the computer, the radar-computer interface equipment and a display console.

A. RADAR SYSTEM

A suitable radar system would be one which could continually track the target, possess good target resolution

characteristics and exhibit a high degree of tracking accuracy. It should have a pulse repetition frequency low enough to prevent range ambiguities, but one high enough to permit the discovery of any high frequency spectral components present in the energy returned from the target. It should also be capable of generating internally those data signals required in the computation of a target's radar cross section. Finally, the radar receiver should possess a large dynamic range to permit various size targets to be tracked through widely different ranges. Dynamic range restrictions can be reduced by the use of radars with AGC and/or logarithmic receivers.

The radar used was a target tracking monopulse radar normally employed in the Nike-Ajax Antiaircraft Guided Missile System described in Ref. 3. The Nike-Ajax is an old system, however the principles used in its implementation apply to any target tracking radar. It was chosen since, of the available radars, it best exhibits the characteristics above. An especially attractive feature of the Nike-Ajax is that it is equipped with an N/A Data Buffer, described in Refs. 4 and 5, which converts analog signals representative of range to the target to digital format. It also samples and stores digital values of azimuth and elevation available from the shaft angle encoders located on the radar antenna pedestal. Another feature of the Nike-Ajax radar installation at NPS is its interconnection with the UPS-1 search radar described in Ref. 6. The output of

the UPS-1 is displayed on a planned position indicator (PPI) installed in the Nike-Ajax radar console. An electronic cross displayed on the PPI indicates the Nike-Ajax radar azimuth and range gate position facilitating acquisition, with the Nike-Ajax radar, of a target detected by the UPS-1 radar. Also, a television system has been installed in the Nike-Ajax radar system which allows rapid acquisition of radar calibration spheres and identification of targets at close range. The television camera is mounted on the radar antenna such that its viewing area center remains aligned with the line of sight of the radar antenna. The television monitor is installed in the radar console. All data signals required to calculate RCS were available in the radar; however, some signal processing was required to transform these data into a form acceptable as an input to the computer. For calculation of average cross section using AGC as a measure of received power, no modifications to the radar were required since it could be used in its normal mode of operation. In attempting to calculate pulse-by-pulse RCS it was necessary to disable the AGC circuit so that the height of the video pulse would serve as an accurate measure of the received power. This was a simple operation since the radar is capable of being operated in two modes. The normal mode uses AGC and the alternate mode uses manual gain control (MGC). Operation in the MGC mode would have provided video signals which could be used for calculations of pulse-by-pulse RCS, however, it was

discovered that the radar's tracking ability was severely degraded in that mode. It tended to lose track quite easily on small targets due to target fluctuation which was not compensated by the AGC since it was disabled. Some method had to be found which would allow operation of the radar using AGC in the tracking circuits, but which made video signals available which were unaffected by AGC. This was accomplished by dividing the received signal at the output of the intermediate frequency (IF) preamplifier. Half the power in the signal was sent to the radar's linear IF amplifier, including AGC, and video circuits. The other half of the received signal power was diverted to another linear IF amplifier, unaffected by AGC, followed by a video detector similar to those normally used in the radar. In this way, the radar could use AGC to maintain its tracking capability and still produce an external video pulse unaffected by AGC and suitable for use in calculating pulse-by-pulse radar cross section. The major deficiency in this arrangement was the insufficient dynamic range of the external receiver unit. The solution to this problem was to substitute a logarithmic IF amplifier with a built-in video detector for the linear IF amplifier and video detector in the external receiver. The amplifier used was a model LST-6010, manufactured by RGH Electronics Laboratory, having a dynamic range of 80 dB. A less acceptable approach would have been to design a manual gain control circuit with fixed selectable values of gain in order to keep the values of target signals

within the calibrated dynamic range of the external linear receiver. Since the power into the radar's sum channel was reduced by one half to provide signal power to the external receiver, the signals in the azimuth and elevation error channels of the radar also had to be reduced by one half by the addition of three-dB pads. This was necessary to maintain the original tracking servo bandwidths, since the gains in the azimuth and elevation error channels depend upon the gain of the sum channel and enters directly in the servo loop gain for angle tracking.

B. COMPUTER

A suitable computer would be one which is capable of receiving input data in the form of analog or digital signals, calculating the required quantities and sending outputs to a display system. It should have input and output trunks to serve peripheral equipment and be capable of generating and receiving signals for synchronizing the radar and computer. The minimum sampling rate of the computer is specified by the pulse repetition frequency (PRF) of the radar if pulse-to-pulse RCS is to be computed on a real-time basis. In addition, the speed of the computer must be sufficient to allow completion of computations associated with one video pulse before the next pulse arrives. Built-in subroutines for curve fitting and evaluating fast Fourier transforms are desirable, although not necessary. Finally, if the computer is not located in the immediate vicinity

of the radar, it is necessary that some means exist for controlling it remotely.

A hybrid computer system consisting of an SDS-9300 digital computer and a CI-5000 analog computer was used in the RCS system, primarily because of its availability in the same building with the radar system. In order to obtain remote control of the computer from the radar location, about 570 feet away, a computer control unit was designed and installed in an unused section of the radar system N/A Data Buffer. The control unit is the third panel from the top in Fig. 1. The unit consists of a ten volt dc power supply and a control panel. Schematic diagrams of the supply and panel are shown in Figs. 2 and 3. Basically, the control panel is made up of switches which, when closed, connect the ten volt supply to the computer input section. A ten volt signal on a particular control line activates a specific mode in the computer program. These signals can be used to direct the computer to desired sections or combinations of sections of the computer program, allowing functional control of the computer. The panel is divided into two sections. The first consists of seven toggle switches which represent seven functions which the computer may be directed to perform. These functions include a display meter calibration routine, calculation of target track information, calculation of RCS based on AGC voltage, and calculation of RCS based on video pulse heights. Lights on the panel indicate which of the control functions are

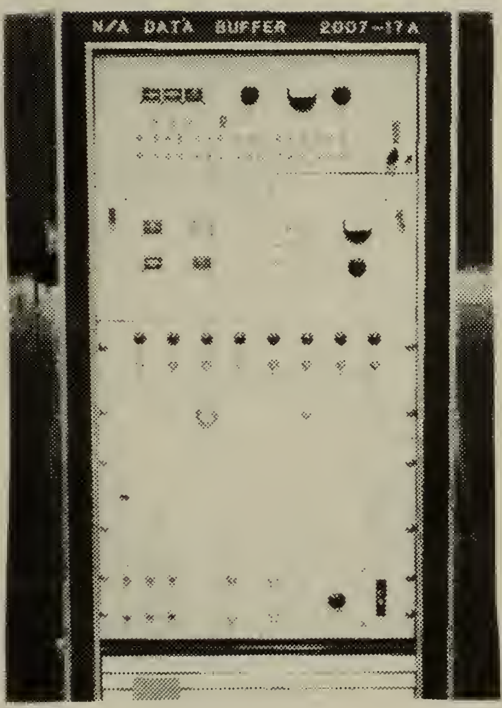

Figure 1. N/A Data Buffer.

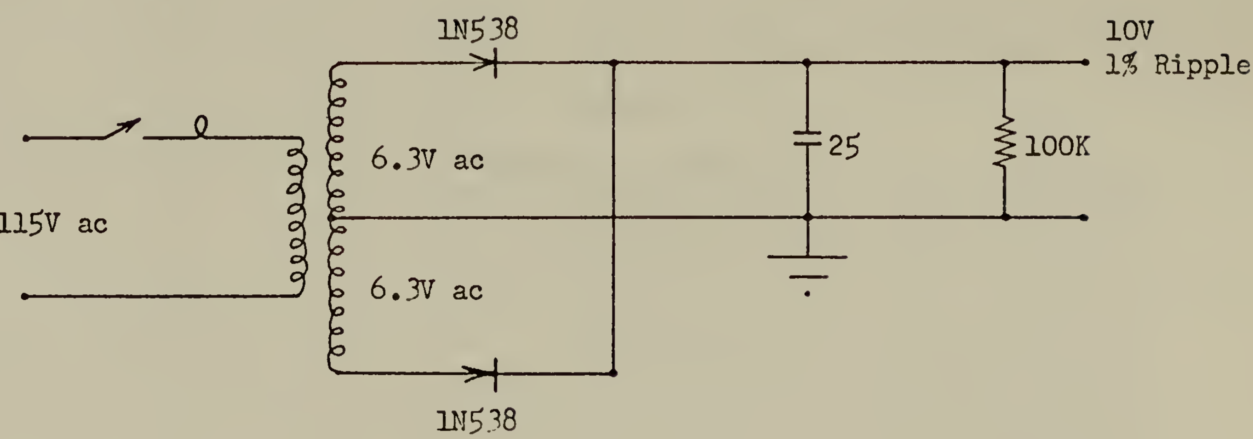

Figure 2. Control Panel Power Supply.

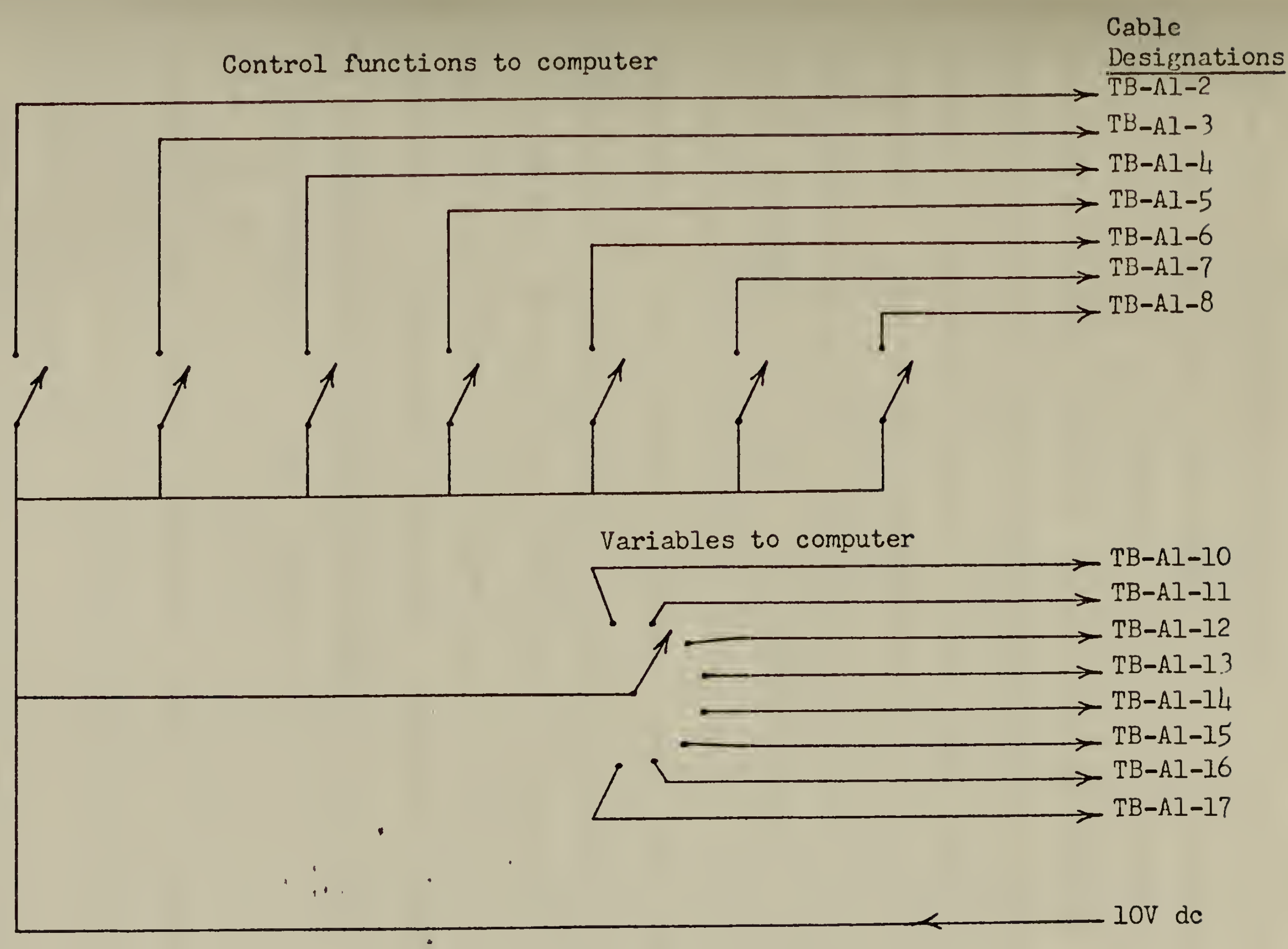

Figure 3. Control Panel Wiring Diagram.

currently in effect. The second section of the control panel consists of a nine-position (including an OFF position) rotary switch labeled VARIABLE which is used to select the parameters to be used by the computer in carrying out a particular function. For example, if the CALIBRATE function switch is on and the VARIABLE switch is in position 1, zero readings should be obtained on all display meters. If the VARIABLE switch is then moved to position 2, full-scale readings on the lowest scale of each meter should be obtained. Table I shows specific functions and parameters which may be selected. Only one function and one parameter may be selected at a time. All seven function switches and all eight parameter positions are connected to the computer although only those listed in Table I were used. The unused functions and parameters were connected for use in causing the computer to construct histograms and calculate FFT's of pulse-to-pulse radar cross sections, as well as for future expansion of the system. However, temporary difficulties in programming the computer to compute video RCS at the 1 kilohertz PRF of the radar reduced the value of the histogram and FFT results to the extent that they were not included in the computer program. Future refinements and expansion of the system are planned which are expected to eliminate this problem.

Target range, azimuth and elevation were available from the radar N/A Data Buffer, but certain signals were required from the computer before the buffer would shift this digital

TABLE I

COMPUTER CONTROL PANEL FUNCTIONS

Function	Variable Setting	Results		
CALIBRATE	1	Provides zero volts to all display devices for calibration purposes		
	2	Provides voltages corresponding to display device readings as follows:		
		target heading	36V	360 degrees
		target angle	36V	360 degrees
		x-track	3V	75,000 yards
		y-track	3V	75,000 yards
		target altitude	10V	5,000 feet
		average RCS	10V	50 sq. meters
		target speed	25V	500 knots
		RCS	10V	50 sq. meters
	3	Provides voltages corresponding to display device readings as follows:		
		x-track	-3V	75,000 yards
		y-track	-3V	75,000 yards
		target altitude	50V	25,000 feet
		average RCS	50V	250 sq. meters
		target speed	50V	1,000 knots
		RCS	50V	250 sq. meters
TARGET TRACK	0	Causes the computer to calculate target heading, angle, speed, altitude and rectangular coordinates. These values are displayed on the display console in the radar room		
AGC RCS	0	Causes the computer to calculate RCS based on AGC voltage. Both average and instantaneous values of RCS will be displayed in the radar room		
VIDEO RCS	0	Causes the computer to calculate RCS based on video pulse height. Both average and instantaneous values of RCS will be displayed in the radar room.		

information onto its output transmission lines. In addition it was necessary to synchronize the N/A buffer with the computer. In the original Nike-Ajax system, target range, azimuth and elevation were passed from the N/A buffer to a unit called DARS which calculated and displayed target track information. In addition, the buffer provided DARS with a data-ready signal each time its range, azimuth and elevation registers were updated. Upon receipt of the data-ready signal, DARS sent a group of 19 shift pulses to the buffer which caused it to shift the 18 bit target position digital words into the DARS unit. DARS also provided the buffer with a sync signal which controlled the rate at which its registers were updated. Since the CI-5000 and SDS-9300 computers were required to communicate with the N/A buffer, programming was necessary to cause the computer to originate shift and sync signals. Details of computer programming are contained in Ref. 7.

C. RADAR-COMPUTER INTERFACE

Figure 4 shows a block diagram of the entire RCS system including line diagrams of signals passing between the radar equipment and the computer. As previously indicated, some of these quantities required processing between the radar and computer to place them in a usable format. This section describes the signal processing which was accomplished.

In order to calculate video RCS, the voltage level of the peak of the video pulses had to be sampled by the computer. The acquisition time of the analog to digital

converters built into the computer was too large to allow accurate sampling of the 200 nanosecond video pulse. Therefore, it was necessary to design a holding circuit, shown in Fig. 5, which would provide the computer with a dc level proportional to the peak voltage of the pulse. Also, since sampling of each individual pulse was desired, a means of resetting the dc output level to zero before receiving the next pulse had to be included in the circuit. This was accomplished by using a 5,000 yard, 30 microsecond range gate available from pin 3, tube V12A in the Nike-Ajax track range amplifier control group, to trigger a monostable multivibrator. The output of the monostable was connected to the base of a 2N3606 transistor which provided a low impedance discharge path for the 3300 pF holding capacitor when turned on 15 microseconds prior to arrival of the next video pulse. Seven microseconds before arrival of the next pulse, the output of the monostable reset to zero, turning the transistor off and providing an infinite impedance to the charge on the holding capacitor. Video responses from targets along the radar line of sight not being tracked by the radar were eliminated by installing a gating emitter-follower transistor circuit at the input to the holding circuit. The portion of the video signal coincident with a 500 yard, 3 microsecond range gate, available at pin 6 tube V2 in the Nike-Ajax range error converter, was allowed to pass through the FET gate to the holding circuit. Signals outside the gate were blocked. Timing relationships between pulses in this circuit

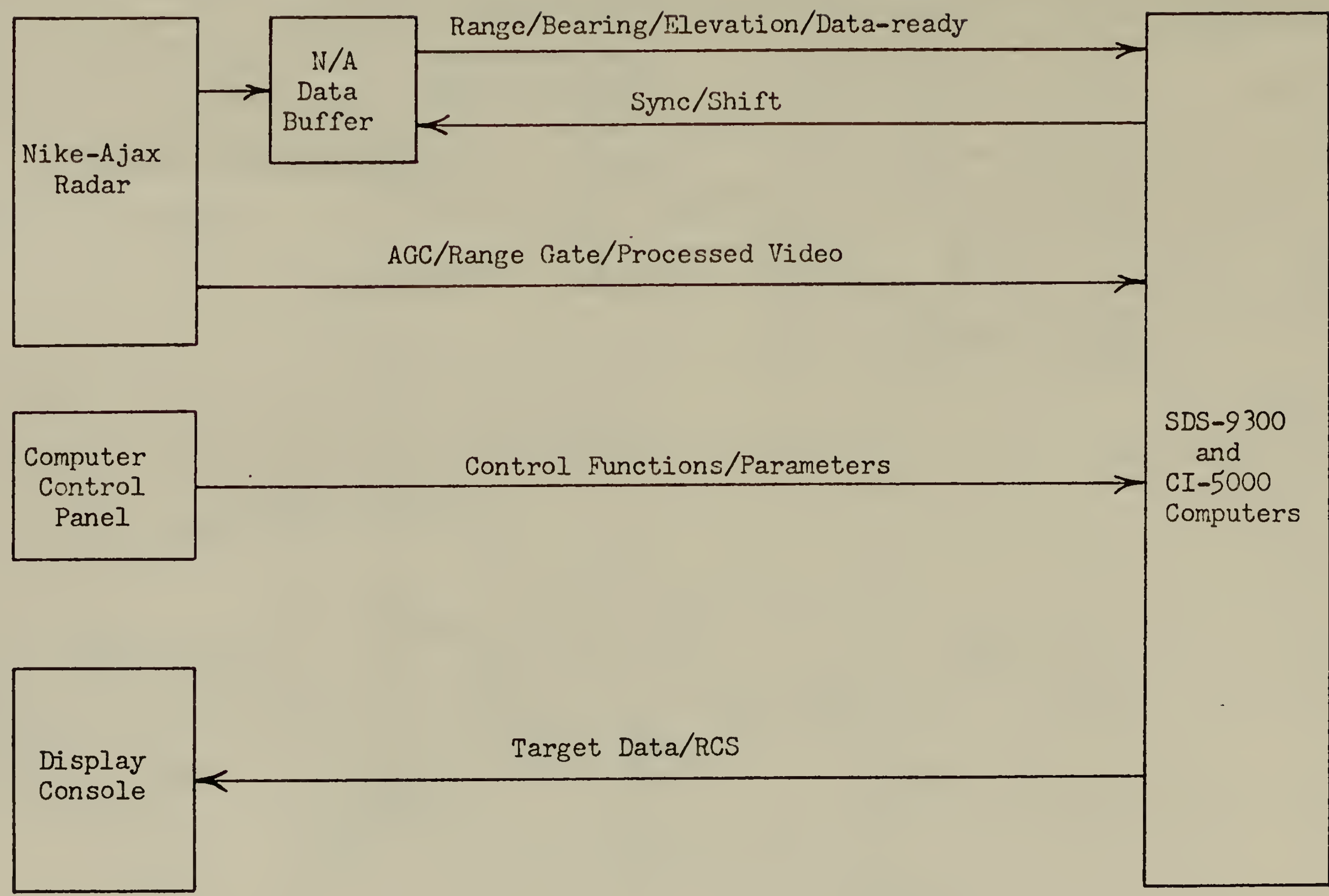

Figure 4. Block Diagram of RCS System.

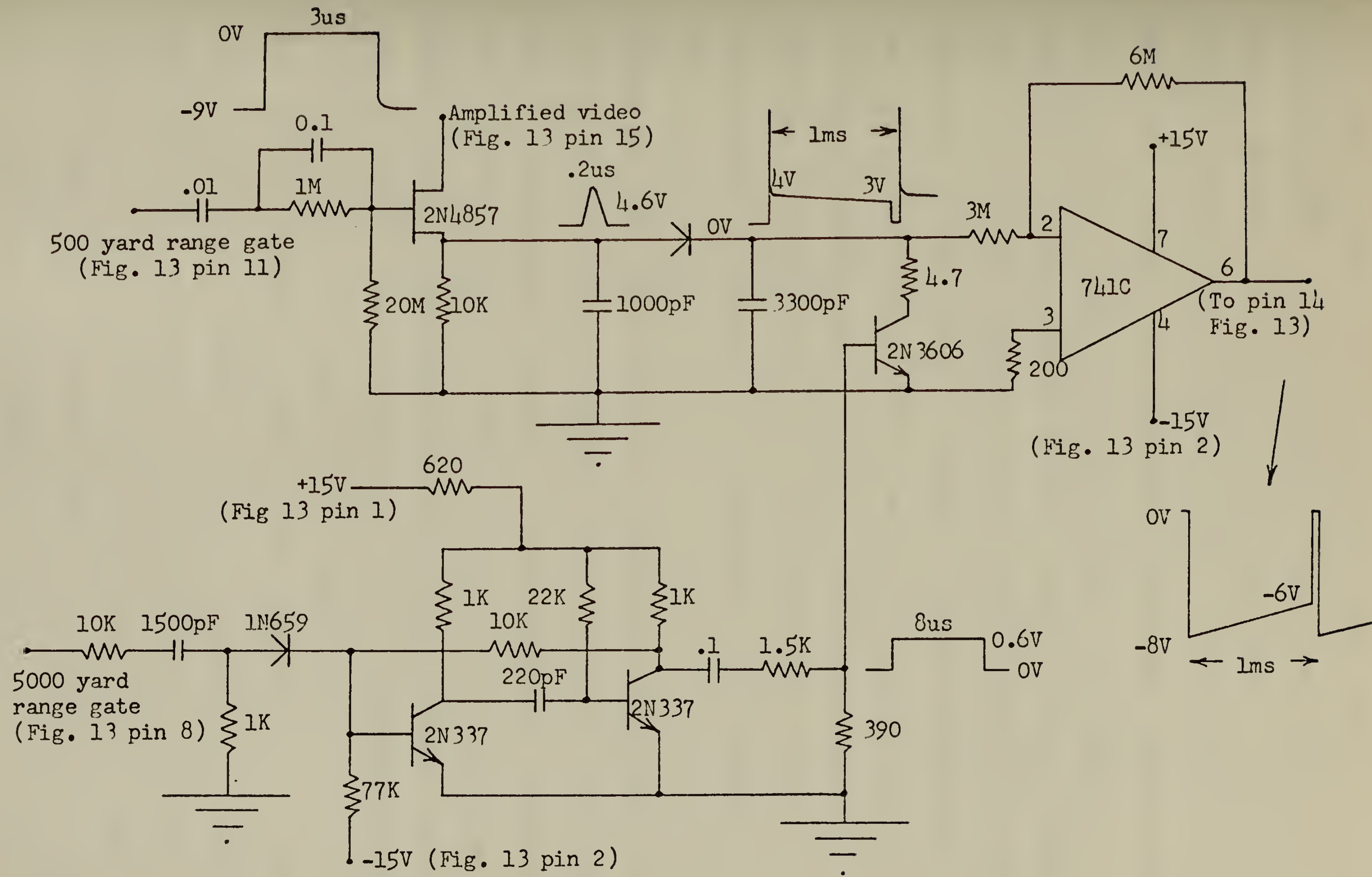

Figure 5. Video Holding Circuit.

are shown in Fig. 6. To improve the performance of the holding circuit, a video amplifier was constructed and connected between the output of the logarithmic IF amplifier and the input to the holding circuit. The addition of this amplifier boosted the maximum 2.5 volt video output of the logarithmic IF amplifier to six volts. For impedance matching, a video emitter-follower circuit with a voltage gain of 0.975 was constructed and placed between the video amplifier and the holding circuit. The video amplifier and emitter-follower are modified versions of those described in Ref. 8 and are shown in Fig. 7. Waveforms shown in Fig.5 and Fig. 7 were obtained by using the radar's built-in test target section adjusted to a frequency of 60 megahertz and with an attenuation setting of 11 dB. The 25 volt power supply for the video amplifier and emitter-follower is shown in Fig. 8. Finally, an Archer 741C operational amplifier with a voltage gain of minus 2.33 was added at the output of the holding circuit to buffer and amplify the processed video signal. The output of the amplifier ranged from zero to a saturation value of minus 12 volts. A block diagram of the entire video signal processing system is shown in Fig. 9. As indicated in Fig. 6, the output of the holding circuit was not a constant valued dc voltage, but drooped significantly. Therefore it was necessary to provide a timing mark to the computer so that the holding circuit output for each pulse could be sampled at the same point in time in relation to the time of occurrence of the video

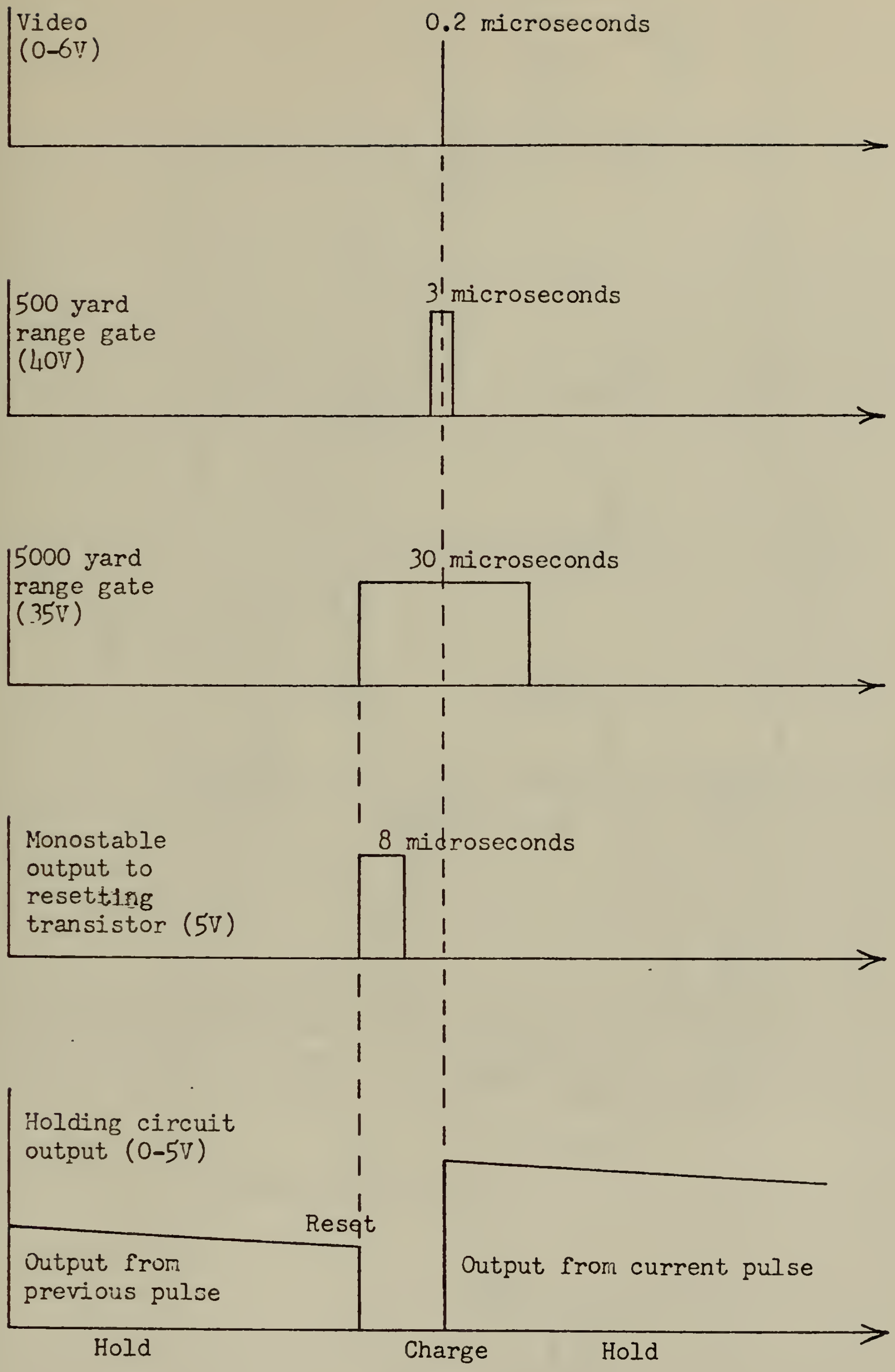

Figure 6. Holding Circuit Pulse Relationships.

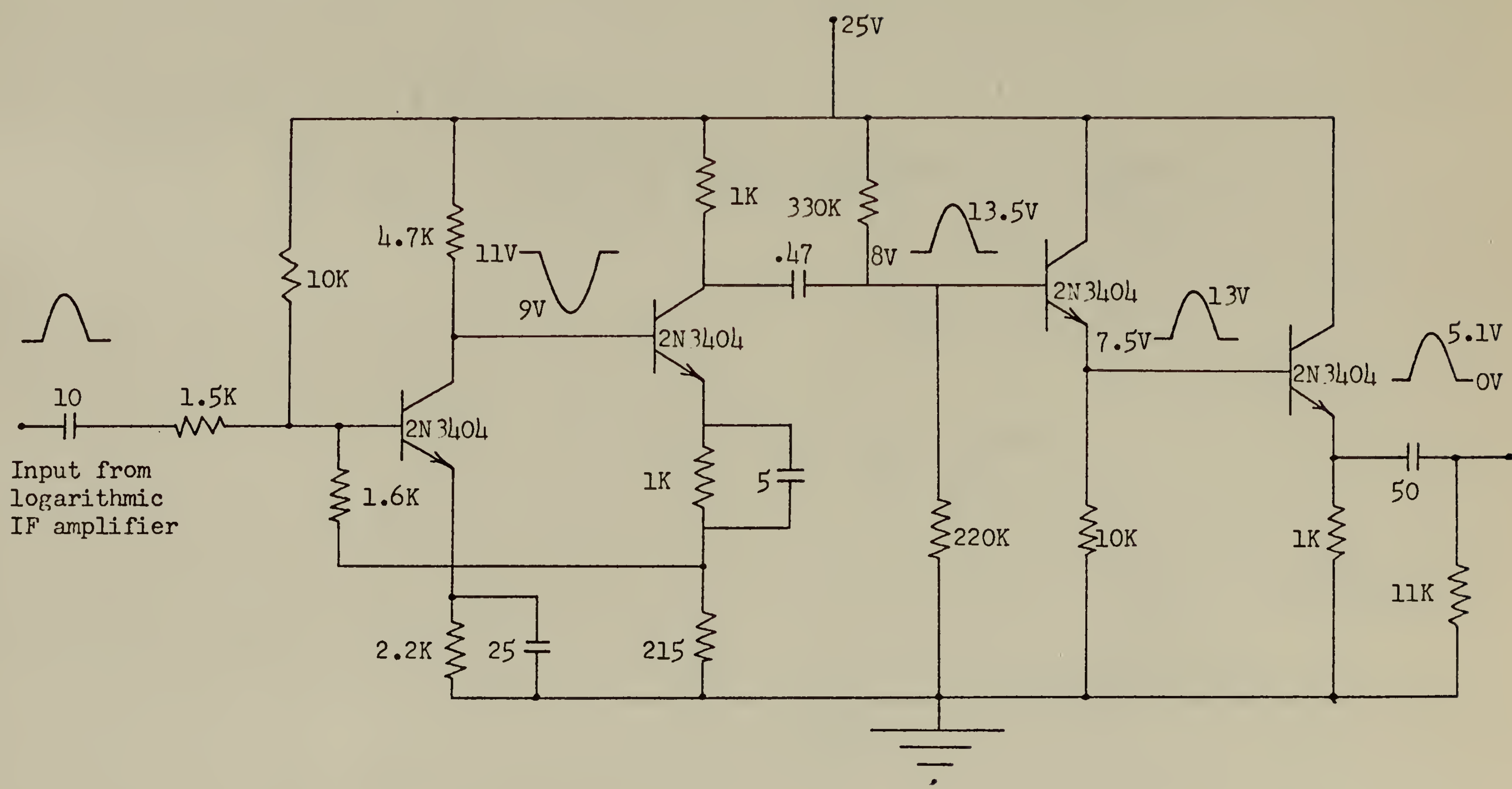

Figure 7. Video Amplifier and Emitter-Follower.

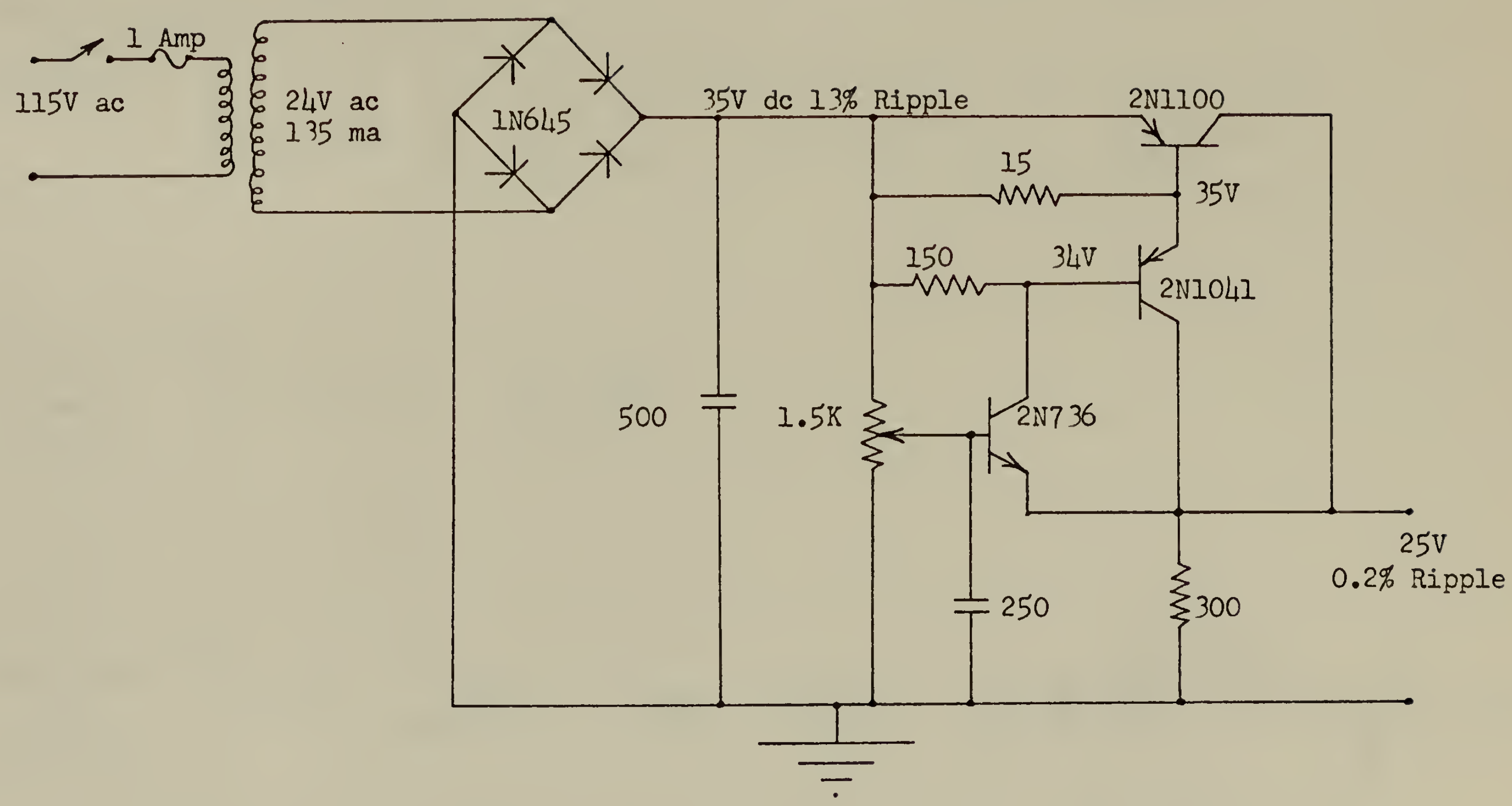

Figure 8. 25 Volt Power Supply for Video Amplifier.

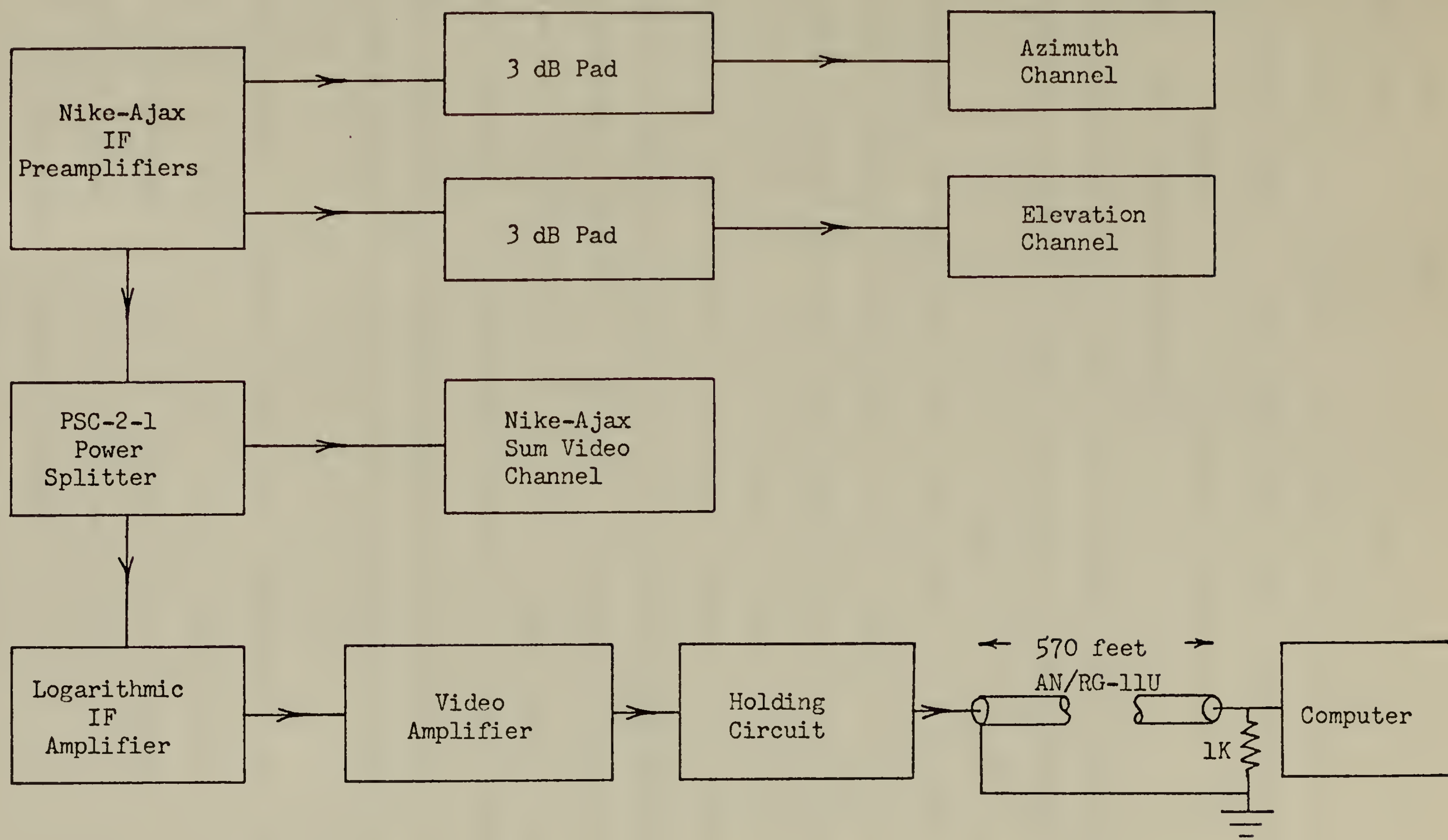

Figure 9. Video Signal Processing System.

pulse. This requirement was satisfied by providing the computer with a 5,000 yard, 30 microsecond range gate available at pin 3, tube V12A in the Nike-Ajax track range amplifier control group. The radar range gate line driver shown in Fig. 10 was used to drive the gate through a 75 ohm coaxial cable to the computer.

For computation of radar cross section using the AGC voltage as a measure of power received, the AGC voltage available in the radar at pin 9 of plug 2 in the AGC section was buffered and amplified using the Archer 741C operational amplifier, having a voltage gain of 2.6, shown in Fig. 11. The amplified and inverted AGC signal was sent to the computer for sampling via a 75 ohm coaxial cable. No conditioning or processing was required for other signals sent to the computer except for installation of transmission line terminating resistors listed in Table II. Figure 12 is a circuit diagram of the dual polarity 15 volt dc power supply used in conjunction with the AGC voltage amplifier, video holding circuit, logarithmic IF amplifier and range gate line driver. All signal processing circuits were installed in the lower section of the display console equipment rack. A diagram of this section is shown in Fig. 13. Terminal strip coding is defined in Table III. Power for the logarithmic IF amplifier was obtained by using a 270 ohm series resistor to reduce the output of the 25 volt power supply to 12 volts and a 56 ohm series resistor to reduce the output of the minus 15 volt power supply to minus 12 volts.

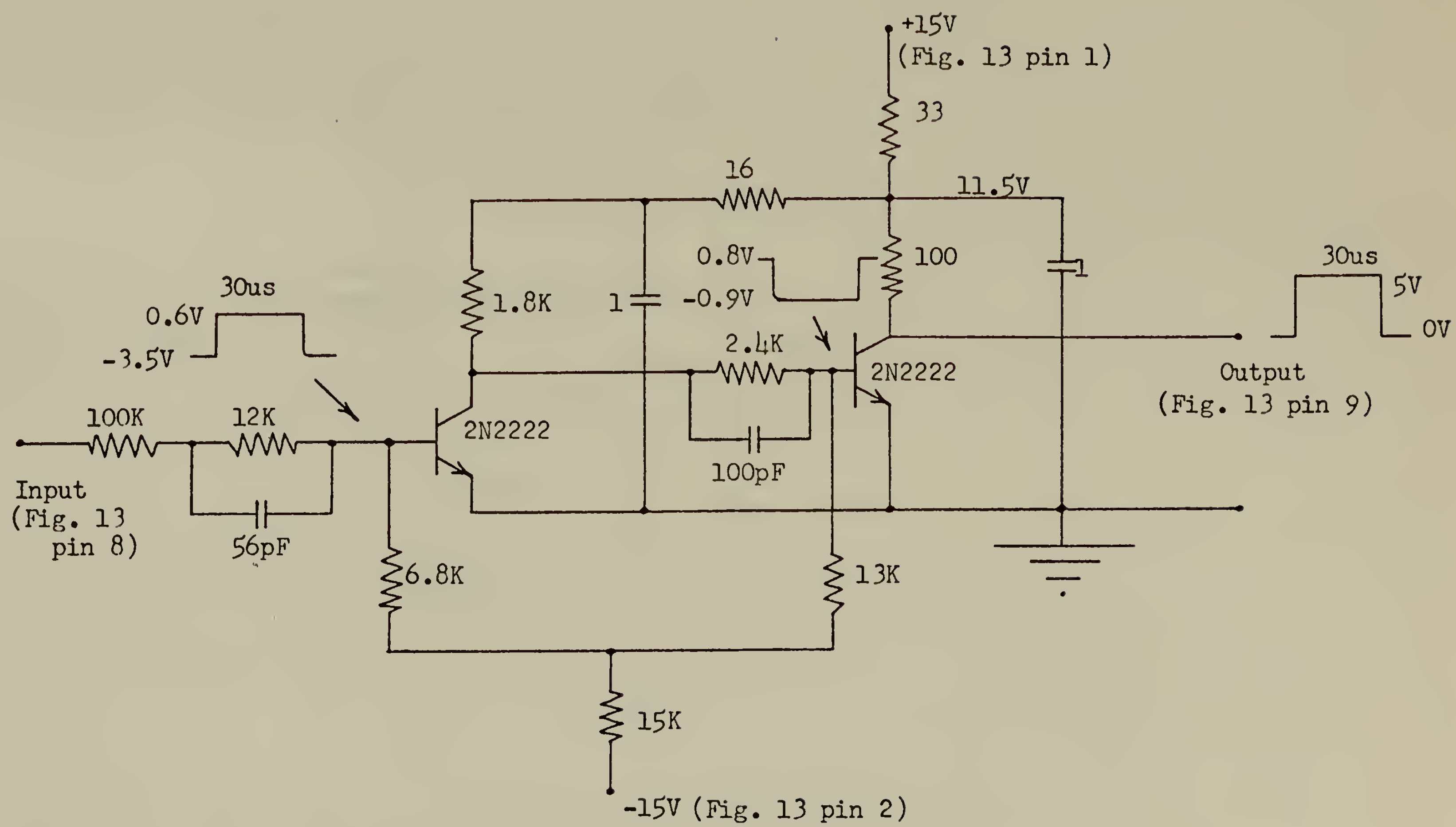

Figure 10. Radar Range Gate Line Driver.

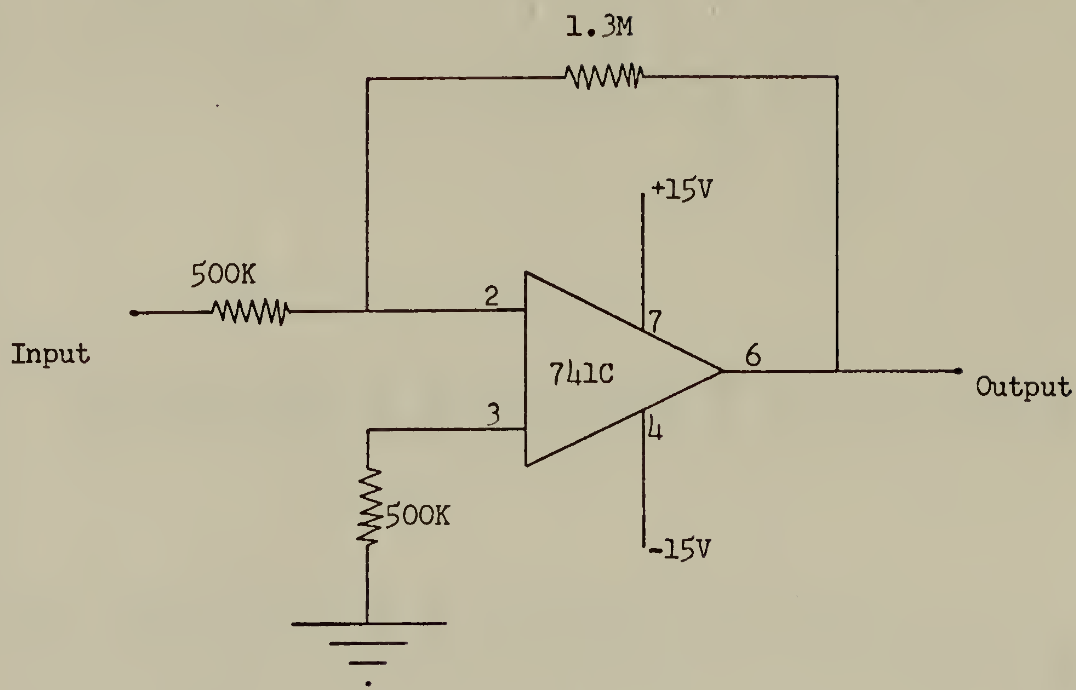

Figure 11. AGC Amplifier.

TABLE II

CABLES FROM RADAR TO COMPUTER

Function (Radar to Computer)	Computer Trunk	Cable Number	Termination
AGC	T074	G-0540	1 K
Video	T075	H-0560	1 K
Range Gate	T076	I-0570	75 ohms
Range	T077	C-0380	75 ohms
Azimuth	T200	A-0090	75 ohms
Elevation	T201	B-0370	75 ohms
Data Ready	T202	F-0450	75 ohms
Calibration Control	T203	TB-A1-2	51 K
Target Track Control	T204	TB-A1-3	51 K
AGC RCS Control	T205	TB-A1-4	51 K
Video RCS Control	T206	TB-A1-5	51 K
Unused Control	T207	TB-A1-6	51 K
Unused Control	T210	TB-A1-7	51 K
Unused Control	T211	TB-A1-8	51 K
Unused Control	T212	TB-A1-9	51 K
Variable 1	T213	TB-A1-10	51 K
Variable 2	T214	TB-A1-11	51 K
Variable 3	T215	TB-A1-12	51 K
Variable 4	T223	TB-A1-13	51 K
Variable 5	T224	TB-A1-14	51 K
Variable 6	T220	TB-A1-15	51 K
Variable 7	T221	TB-A1-16	51 K
Variable 8	T222	TB-A1-17	51 K
Spare	T225	-	-
Phone	-	TB-A1-18/19	-

Note: TB-A1-1 is ground for all control functions and variables.

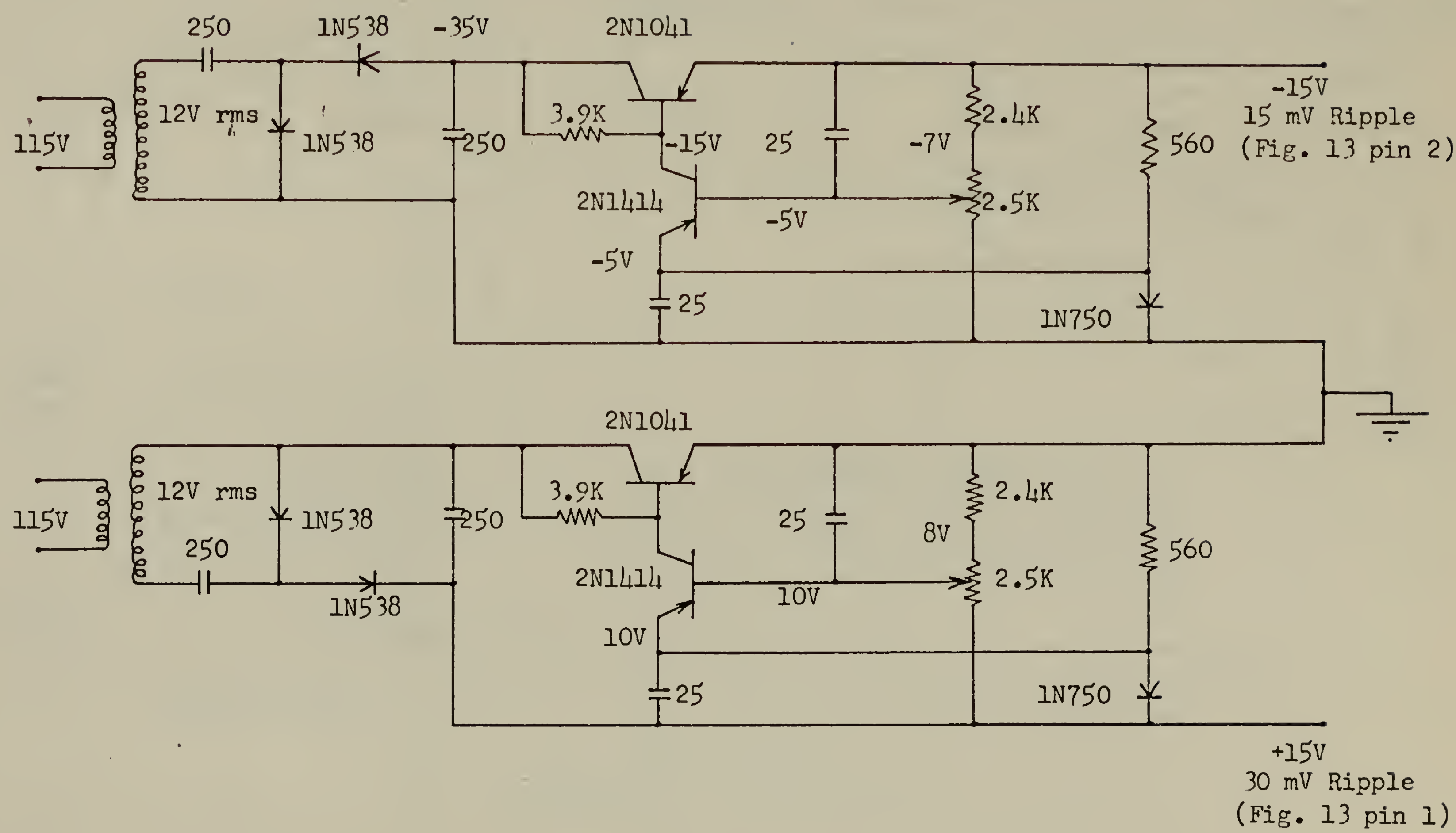

Figure 12. Dual Polarity 15 Volt Power Supply.

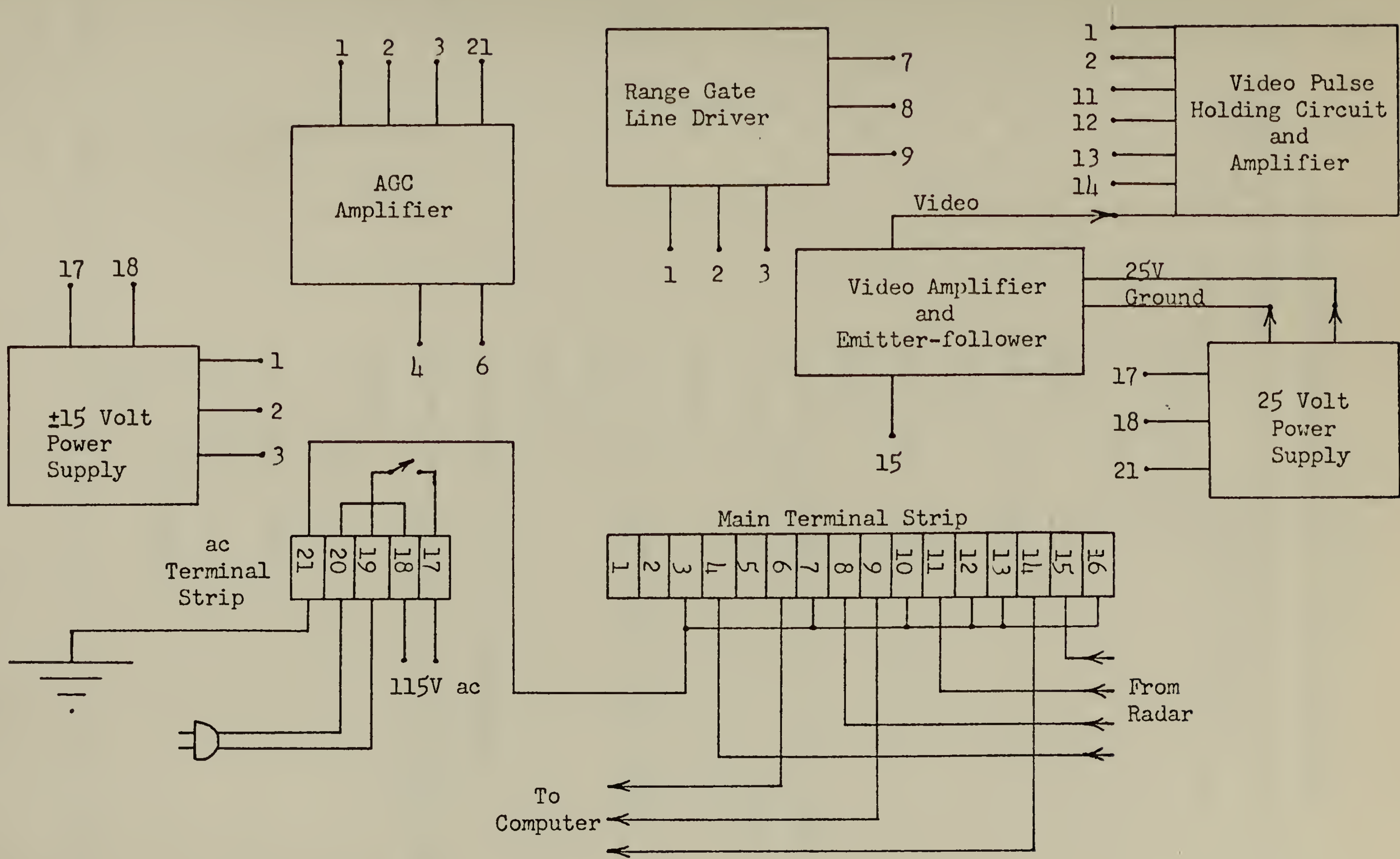

Figure 13. Display Console Signal Processing Section.

TABLE III

DISPLAY CONSOLE TERMINAL IDENTIFICATION

Terminal	Identification
1	+15 Volts dc
2	-15 Volts dc
3	Ground
4	AGC from radar
5	Unused
6	Amplified AGC to computer
7	Ground
8	5,000 yard range gate from radar
9	5,000 yard range gate to computer
10	Ground
11	500 yard range gate from radar
12	Ground
13	Ground
14	Processed video to computer
15	Video from logarithmic IF amplifier
16	Ground
17	115 volts ac
18	115 volt common
19	115 volts ac
20	115 volt common
21	Ground

D. DISPLAYS

A console was composed of suitable devices for display of values calculated by the computer. No interface equipment was required for signals passed from the computer to the display unit except for terminations shown in Table IV. Since all output signals from the computer were through its digital to analog converters, only analog voltage measuring devices were used for display purposes. The particular devices used were five Knight model 924 ten volt dc panel meters, a Hewlett Packard (HP) model 7035B X-Y recorder, a HP model 130BR oscilloscope and a HP model 680 strip chart recorder arranged as shown in Fig. 14.

The panel meters were used to display target heading, angle, altitude, speed and average RCS. Each meter circuit was configured as shown in Fig. 15 to provide optimum scales for display of target information. Scales could be selected using rotary switches installed beside each multi-scale meter. For overload protection, a 12 volt, ten watt zenier diode was connected across the terminals of each meter. As an additional safety factor, the selector switch for each meter included an OFF position. Average RCS was obtained by calculating values of RCS based on either AGC voltages or video pulse peak voltages and averaging these values in groups of 1,000 cross sections each. Values of target heading, angle, altitude and speed were calculated using changes in the values of target range, azimuth and elevation.

TABLE IV

CABLES FROM COMPUTER TO RADAR

Function (Computer to Radar)	Computer Trunk	Cable Number	Termination
RCS	T174	J-0580	Oscilloscope
Average RCS	T175	K-1520	Meter/Strip Chart
Unused	T176	L-2010	Scope/Strip Chart
Target Heading	T177	M-2050	Voltmeter
Target Speed	T300	N-2060	Voltmeter
Target Altitude	T301	O-2061	Voltmeter
X-Track	T302	P-2062	X-Y Recorder
Y-Track	T303	Q-2063	X-Y Recorder
Target Angle	T304	R-2064	Voltmeter
Sync Signal	T305	E-0400	75 ohms
Shift Signal	T306	D-0390	75 ohms
Spare	T307	-	-

X and Y coordinates for the target's instantaneous position were calculated and sent to the X and Y terminals of the X-Y recorder resulting in a display of the target's track. A scale of 25,000 yards per inch and one volt per inch was used. A maximum range of 100,000 yards can be plotted.

The oscilloscope was connected to a five-position rotary switch so that amplified AGC voltage, instantaneous RCS, or the output of the video holding circuit could be displayed.

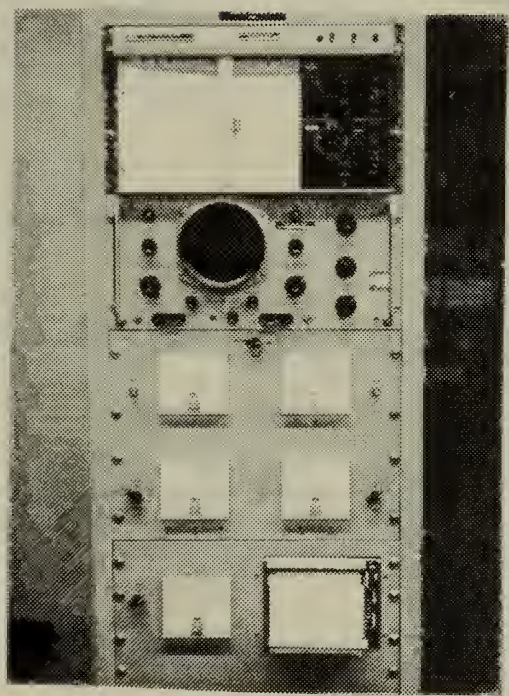

Figure 14. Display Console.

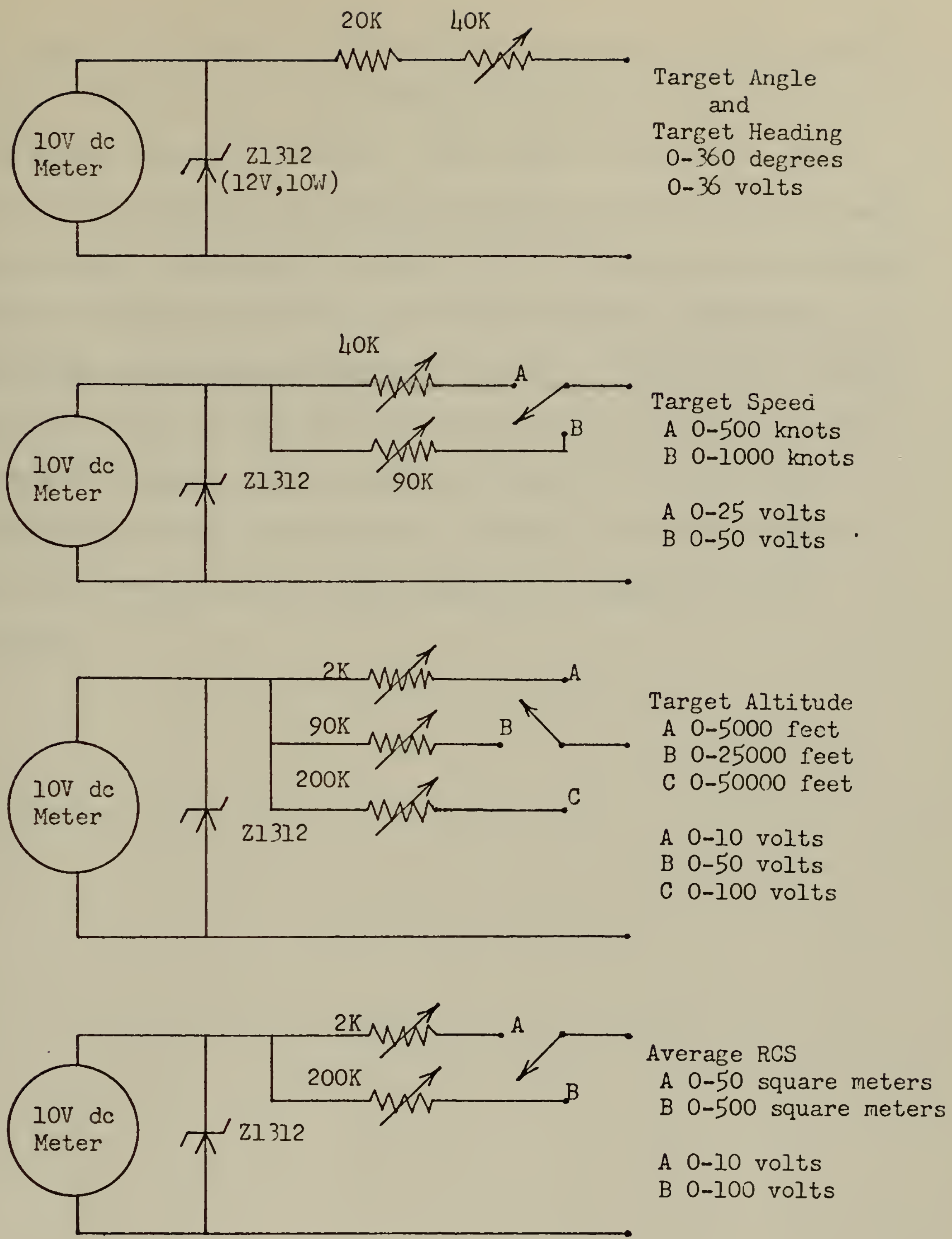

Figure 15. Panel Meter Wiring Diagrams.

One position labeled FFT/HIST was connected to the unused cable, L-2010, from the computer for future display of histograms and FFT results. The fifth position on the switch disconnects all inputs from the oscilloscope's rear panel input terminals to allow use of the scope with miscellaneous inputs using the normal front-panel terminals. A four-position rotary switch was used to connect the strip chart recorder for display of either average RCS or amplified AGC voltage. One position labeled FFT/ HIST is connected to the unused cable, L-2010, from the computer and the fifth position disconnects all inputs to the recorder.

IV. OPERATIONS

The basic theory described in the Theory section was applied in the implementation of the system. However, the mechanics involved in the application of the theory were different for calculation of RCS based on AGC voltage and RCS based on video pulse height.

For AGC cross sections, a calibration track was conducted using a metal calibration sphere having a six inch diameter. Values of AGC voltage and range were recorded, from which a plot of AGC voltage versus range to the sphere was constructed. A polynomial equation fitting the curve and providing a relationship between AGC voltage and range to the sphere was stored in the computer as a calibration function. The radar cross section of the sphere was calculated to be 0.018 square meters using equation (5) and included in the computer program. Airborne targets were then tracked with the radar and instantaneous values of AGC voltage and range to the target were sampled by the computer. The polynomial equation obtained during the calibration track was entered with each value of AGC voltage to obtain a corresponding range to the sphere. The known values of range to the target, cross section of the sphere and the corresponding range to the sphere were used in equation (4) to calculate the radar cross section of the target on a real-time basis.

For radar cross sections calculated using video pulse height information, different mechanics were used to implement the theory. The video signal processing system including the logarithmic IF amplifier, video amplifier and emitter-follower, holding circuit and amplifier, and coaxial cable to the computer shown in Fig. 9 was calibrated using an RF Communications Incorporated Model 808 signal generator set at the radar's IF of 60 megahertz. Pulsed IF signals (200 nanoseconds) of known power in decibels relative to a milliwatt were put into the logarithmic IF amplifier and corresponding values of processed video pulse height were recorded at the computer. A system calibration curve similar to the one shown in Fig. 16 was constructed. Although not a part of the calibration procedure, values of output voltage from the video amplifier and the logarithmic IF amplifier for known values of power put into the system were also plotted. Straight line equations fitting the calibration curve and providing a relationship between processed video pulse height, V_p, in volts and power received at the input to the logarithmic IF amplifier, P_r in dBm was stored in the computer as a calibration function. Using this function, P_r in dBm could be found for known values of V_p. Furthermore, P_r in milliwatts could be determined from the relation

$$P_r \text{ in dBm} = 10 \log_{10} (P_r \text{ in milliwatts}) \tag{6}$$

which may be written as

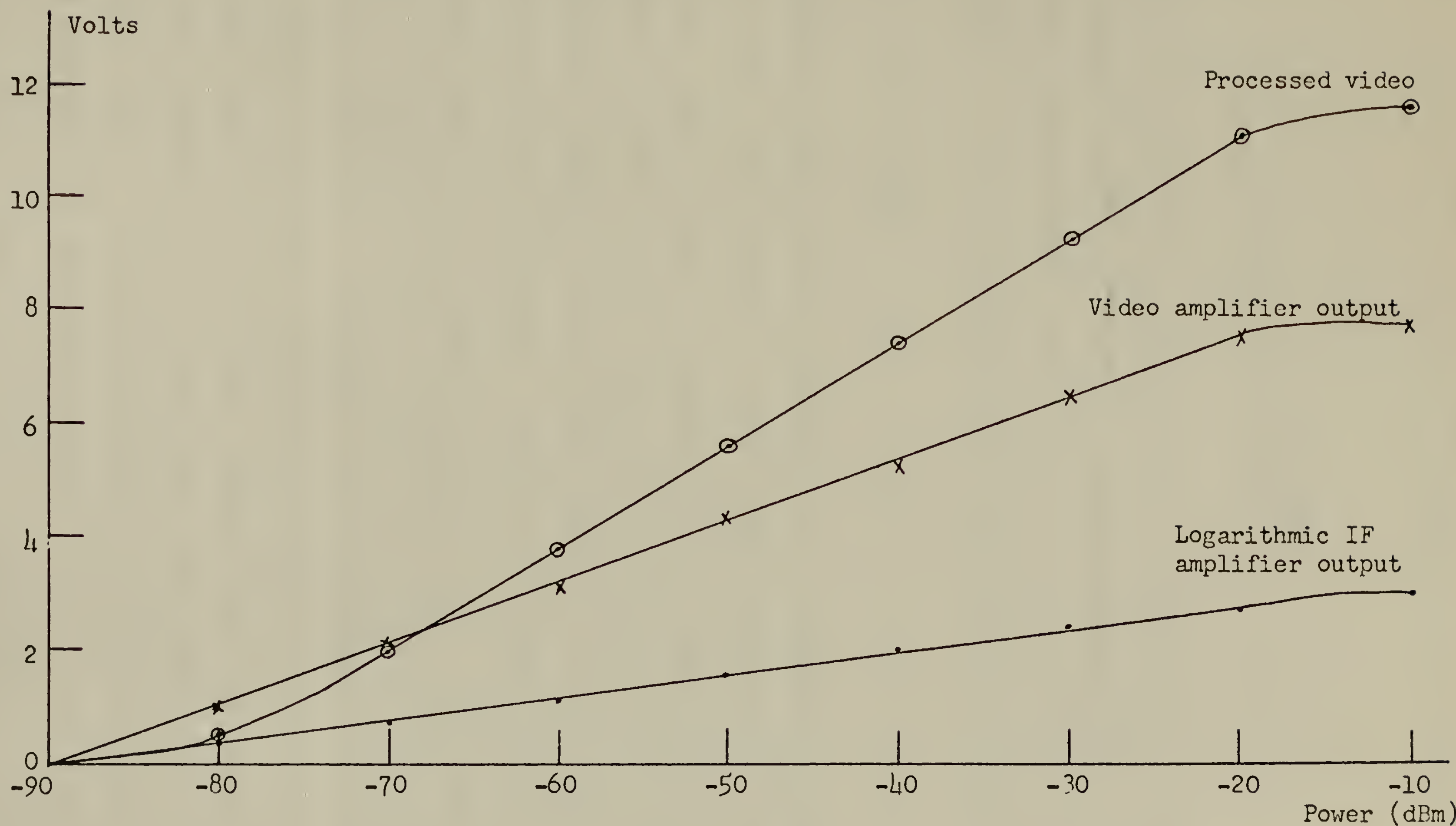

Figure 16. System Calibration Curves.

$$P_r \text{ in dBm} = (10)(0.43429)\log_e(P_r \text{ in milliwatts}) \quad (7)$$

or

$$P_r \text{ in milliwatts} = e^{\frac{P_r \text{ in dBm}}{4.3429}} \quad (8)$$

In the radar equation, equation (2), values of P_t, G and A were assumed constant from one calibration period to the next and were combined with the $(4\pi)^2$ term to form a system constant, C. The radar equation could then be written as

$$P_r = C \frac{\nu}{R^4} . \quad (9)$$

To determine the system constant, C, a calibration sphere of known radar cross section (0.018 square meters) was tracked with the radar. Since P_t varies with the radar PRF and magnetron current, these values were recorded during the calibration tracking run so that identical values could be used during RCS measurement. Typical recorded values were 924 hertz and five milliamps respectively. Instantaneous values of processed video voltage and range to the sphere were also recorded. Processed video voltages were used in the system calibration function equation to determine values of power received, P_r in dBm. These values were converted to power received, P_r, in milliwatts using equation (8). Several values of the system constant were then calculated using equation (9) and known values of P_r, ν and R for the sphere. These values were averaged to determine a single value of C, typically 7.93×10^9 milliwatt-(meters)^2, for use

during RCS measurement. Airborne targets were then tracked with the radar and instantaneous values of processed video voltage and range were sampled simultaneously by the computer. Processed video voltage was converted to power received using the system calibration function and equation (8). The radar cross section of the target based on video pulse height was calculated from equation (9) using the known values of P_r, C and R. A computer sampling rate of 924 hertz would have resulted in the real-time measurement of radar cross sections on a pulse-by-pulse basis; however temporary programing difficulties mentioned previously resulted in a maximum rate of about 250 hertz.

V. AREAS FOR IMPROVEMENT

The RCS measurement system designed and assembled is capable of measuring and displaying radar cross section based on AGC voltage, radar cross sections based on video pulse height and target information such as target angle, target altitude, target heading, target speed and a plot of the target's track. Areas for improvement to meet the specific goals originally established for the final system include modification of the computer program to obtain RCS measurement on a pulse-by-pulse basis and the addition of subroutines for construction of RCS histograms and calculation of fast Fourier transforms using radar cross sections measured at the PRF of the radar. These additional features would provide a capability for determining target signature information. No changes are expected to be required in the radar and radar-computer interface circuits, to accomplish these objectives. Three unused control function switches mounted on the computer control panel in the radar room are connected to computer input trunks T207, T210 and T211. These switches may be used in conjunction with eight parameter settings on the VARIABLE switch to produce up to 24 control signals to the computer. One control function switch could be used to direct the computer to construct a histogram of radar cross sections. The eight parameter settings could be used to specify the number of radar cross

section samples to be used in constructing the histogram. Similarly, another of the unused control function switches could be used to direct the computer to calculate a fast Fourier transform of radar cross sections. The eight associated parameter settings could be used to specify the number of radar cross section samples to be used in the FFT. One AN/RG-11U coaxial cable, number L-2010, is connected from computer output trunk T176 to the oscilloscope and strip chart recorder selector switches on the RCS display console for future use in displaying histograms and FFT's of RCS data. FFT's and histograms could also be displayed as curves on a computer line printer page using a presently documented SDS-9300 program called VPLOT. The third unused control function switch could be used with its associated parameter settings to direct the computer to construct this type of display.

Although FFT and histogram information was not computed, it was determined that the HP model 680 strip chart recorder installed in the RCS display console was impractical for display of histograms and FFT results, since its maximum paper feed speed is eight inches per minute and its full scale response time is one half of a second, requiring too long a time to produce an intelligible display. Also the single track of the recorder prevented the recording of target aspect angle and RCS data at the same time. This detracted from the usefulness of the system since it is important to correlate aspect angle with RCS in analyzing

RCS data. Installation of a dual-track strip chart recorder similar to the Brush model 220 would alleviate both of the above deficiencies. Installation of a three-track recorder and modification of the computer program to include calculation of vertical depression angle from the target to the radar antenna would allow simultaneous recording of vertical depression angle, horizontal target angle and RCS. This would completely define the target aspect and allow its correlation with RCS data.

Another improvement to the system could be made to reduce the manual effort and increase the accuracy associated with entering system calibration data and curves into the computer program. As stated before, calibration information in the form of AGC voltage versus range and processed video voltage versus range for calibration sphere tracking runs are recorded on a strip chart recorder in the computer room. Also, the external radar receiver calibration curve of processed video output versus known input power in dBm is recorded on the same strip chart recorder. Manual calculations are required to determine a system constant, C, to be used in the RCS computer program. Curve fitting routines are used to determine equations of range as a function of AGC voltage and received power as a function of processed video voltage. These equations are then manually put into the RCS computer program. A computer calibration program

could be written which would cause the computer to read periodically sampled values of AGC voltage and range directly into the curve fitting program. The output in the form of coefficients, B(i), in the polynomial equation of the form

$$\text{Range} = B(1) + B(2)AGC + B(3)(AGC)^2 + B(4)(AGC)^3 + \ldots \quad (10)$$

could be read into the RCS computer program using punched cards. The same calibration program could be used to cause the computer to periodically sample and print values of range to the sphere and corresponding values of processed video voltage for use in calculating the system constant, C. Another program could be written which would cause the computer to sample and print values of processed video voltage during system calibration using known values of input power in dBm. The above would completely eliminate use of the strip chart recorder in the computer room as well as errors associated with its use. These errors could be particularly pronounced when using the recorder to measure processed video voltage since the processed video voltage for a particular pulse droops significantly and the computer uses a radar range gate to control the point in time at which it samples the drooping processed video. This point may not be at the mean of the extreme values of voltage for each pulse, however the strip chart recorder does respond at this mean value. That is, for a particular processed video pulse, the result of sampling with the strip chart recorder may not be the same as the result as sampled by the computer.

The display of instantaneous RCS on the oscilloscope contains too much noise, apparently picked-up by the transmission lines between the computer and the display console. About 30 feet of standard twisted-wire electrical conductor used between the coaxial cable junction box in the radar room and the oscilloscope should be replaced with AN/RG-11U coaxial cable.

As shown in Fig. 16, the processed video output versus received power in dBm is not a straight line for input power between -70 and -90 dBm. This is due to the inability of the video holding circuit to respond efficiently to very small video signals. Consideration was given to purchasing a commercial sample-and-hold circuit; however, at the time, no circuit could be found which had sufficient response time to sample the 200 nanosecond video pulse. In the future, additional attempts should be made to purchase such a circuit.

For checking the accuracy of computed RCS, a useful procedure is to loft a balloon and calibration sphere, have the computer calculate radar cross section and compare the result with the 0.018 square meter cross section of the sphere. Since the lowest scale on the average RCS meter is zero to 50 square meters, the RCS of the sphere cannot be read on the meter. Addition of another computer operation mode, controlled by a control function switch setting, which would scale the RCS output of the computer to 100 volts per square meter of RCS would alleviate this problem.

The target track plot, strip chart and panel meters on the display console require addition of illuminating lamps in order to be easily read, since the light level in the vicinity of the radar scopes must be kept low when attempting to acquire targets.

Although the system is capable of measuring RCS of a target, results indicate that additional calibration of the video processing system is required. Elimination of the strip chart recorder in the computer room for recording video calibration curves is expected to produce better results.

Finally, consideration should be given to using a polaroid camera with an oscilloscope adapter to obtain permanent records of instantaneous RCS data, histograms and FFT results of interest.

VI. CONCLUSION

The radar cross section measurement system implemented at NPS has provided a capability for the calculation of calibrated RCS on a real-time basis. Although additional calibration of the system is required to improve the accuracy of computed radar cross sections, system operation has verified the validity of the methods of computing RCS discussed in the Theory section. Capabilities have been achieved for measuring radar cross section of a target based on AGC voltage, measuring radar cross section based on video pulse height, and computing and displaying target track information. Since the system does use two methods for computing RCS, it provides an excellent means for comparison of RCS values obtained. Although the time required to formulate the system prevented the taking of extensive data, it is expected to be useful in examining the nature of radar cross sections of airborne targets.

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ABSTRACT

The instrumentation of a Nike-Ajax radar to perform real-time radar cross section measurements of airborne targets is discussed. Measurements include those based on both radar automatic gain control voltage and radar video pulse peak voltage.

Instrumented signals within the radar are conditioned and sent via transmission lines to a CI-5000/SDS-9300 hybrid computer. Computed radar cross section and associated analysis information are returned to a display console in the vicinity of the radar.

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	ROLE	WT	ROLE	WT	ROLE	WT
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CROSS SECTION						

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